



Casting defects induced fatigue damage in aircraft frames of ZL205A aluminum alloy – A failure analysis

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ABSTRACT

Two different types of aircraft frame components, which had collapsed respectively in their former vibration-fatigue performance tests, were submitted for failure analysis. The two failed frames were both made of aerial material ZL205A, a high-strength cast Al–Cu–Mn–Ti alloy. According to a series of experimental procedures including visual observations, X-ray detections, fractography inspections, microstructure examinations, mechanical tensile tests, hardness measurements and fluorescent penetrating inspections, it was indicated that the fracture was attributed to fatigue cracks which were induced by casting porosity defects at the external surfaces of frames. Numerous fine fatigue striations presented in the vicinity of casting porosities. Especially, it was observed of a special appearance of latitude–longitude crossed fatigue striations on the fracture surface due to the coupled stresses supplied by the former multi-directional vibration tests. The overload fast-rupture regions on fracture surfaces suggested the typical cleavage fracture mode, which was characterized by a number of river patterns and cleavage steps. The intergranular spatial dendrite-shaped casting porosities largely contributed to the local stress-concentrations in matrix materials. Triangular grain boundaries induced by the former casting burnt implied that the intergranular melting phenomenon had occurred. Furthermore, the effect of groove-shaped structure at roots of spatial convex-bodies on the edge of casting porosity was especially analyzed. And the influence of the casting porosity size on fatigue cracks was briefly discussed.

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1. Introduction

Aircraft structural components are always exposed to various inspections to guarantee their service life and for early recognition of inevitable damage by dynamic stresses, especially the ultimate failure by fatigue fracture [1,2]. Al–Cu-based alloys, as a series of high-strength and light-mass structural materials, are intensively used in the aerospace industry. Cast aluminum alloy ZL205A, which is named by Chinese national norm, is a typical cast Al–Cu–Mn–Ti aluminum alloy with primary alloying elements including 4.6–5.3 wt.% Cu, 0.3–0.5 wt.% Mn, 0.15–0.35 wt.% Ti and other minor elements such as Zr, Cd, V and B with their total content of 0.2 wt.%. In the substrate of aluminum alloy, there are also some impurity elements, such as Fe, Si, Mg and Zn. The primary strengthening phase is Al₂Cu, which is primarily solved in α -Al matrix after solution heat treatment. Supersaturated precipitation is commonly eutectic ' α (Al) + θ (Al₂Cu)', sometimes with slight insoluble T (Al₁₂CuMn₂) phase remaining in the interdendritic spaces. After casting, heat treatment, machine tool processing and surface processing, the cast Al–Cu–Mn–Ti aluminum ZL205A is widely

applicable to aircraft frame components due to its outstanding high strength to weight ratio, high strain of toughness, better corrosion resistance, high production efficiency and low waste rate of raw-materials. However, comparing to the conventional cast aluminum of Al–Si series, the cast Al–Cu–Mn–Ti aluminum has poorer casting fluidity and more tendencies of casting defects including shrinkage porosity, alumina skins, entrapped air bubbles, cold fills, casting over-burnt microstructure and the dross or intermetallic inclusions. But in the substrate of Al–Si series cast aluminum alloy, the eutectic Si particles always play a negative role in mechanical properties of materials. The rapid interdendritic propagation of cracks easily occurred because of Si particles existing ahead of the crack tip [3]. By contrast, the casting substrate of ZL205A just has very little Si element.

Porosities in casting are formed by hydrogen precipitation in the liquid solution, contraction during the solidification process, mold–metal reaction, high temperature oxidation, blowholes (cavities, essentially spherical, often not contacting the external casting surface, produced because of gas entrapped in the metal during the course of solidification), and usually by the combination of these effects [4]. And for the fatigue life of aircraft frame components made by casting aluminum alloys, the informed research including experiments and computer simulations have demonstrated that the fatigue resistance is strongly dependent on the casting micro-

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